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Competing for the Mighty Columbia River -
Past, Present and Future: The Role of Interstate Allocation

A View on Idaho's Experience with Flow Augmentation

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1.0 - Introduction

The Columbia River Basin (Figure 1) includes 258,500 square miles in seven western states and British Columbia. Most of the basin is located in the states of Idaho, Oregon, and Washington. The Columbia River Basin generates an average annual runoff of nearly 200 million acre-feet of water, of which about 25 percent originates in the British Columbia portion of the basin. The 1000-mile long Snake River, which flows through the southern and western portions of Idaho into eastern Washington, is a major tributary to the Columbia River, contributing about 37 million acre-feet of water to the average annual runoff.

Figure 1. The Columbia River Basin and Major Northwest Dams

The construction of dams in the Columbia River Basin began in the 1800s. More than 250 significant dams have been constructed in the basin (CRWMG, 1997), making it one of the most highly developed river basins in the world.

1.1 - The Decline of Snake River Chinook Salmon

The history of the Columbia River Basin has also witnessed the decline of the region's salmon. It has been estimated that in the 1800s, the Snake River portion of the basin alone produced in excess of 1.5 million adult spring and summer chinook salmon. By the mid-1900s, the numbers declined by more than 90 percent, and the numbers of returning wild fish have since declined by an additional 90 percent (Matthews and Waples, 1991). Figure 2 shows the decline in the numbers of adult and jack spring and summer chinook and fall chinook returning to the Snake River since 1969, as counted at Ice Harbor Dam (the first dam on the Snake River above its confluence with the Columbia River) (WDFW/ODFW, 1996). The wild stocks of Snake River spring and summer chinook and fall chinook, as well as sockeye salmon, have shrunk to such critically low numbers that all three species were listed as threatened under the Endangered Species Act (ESA) in 1991 and 1992.

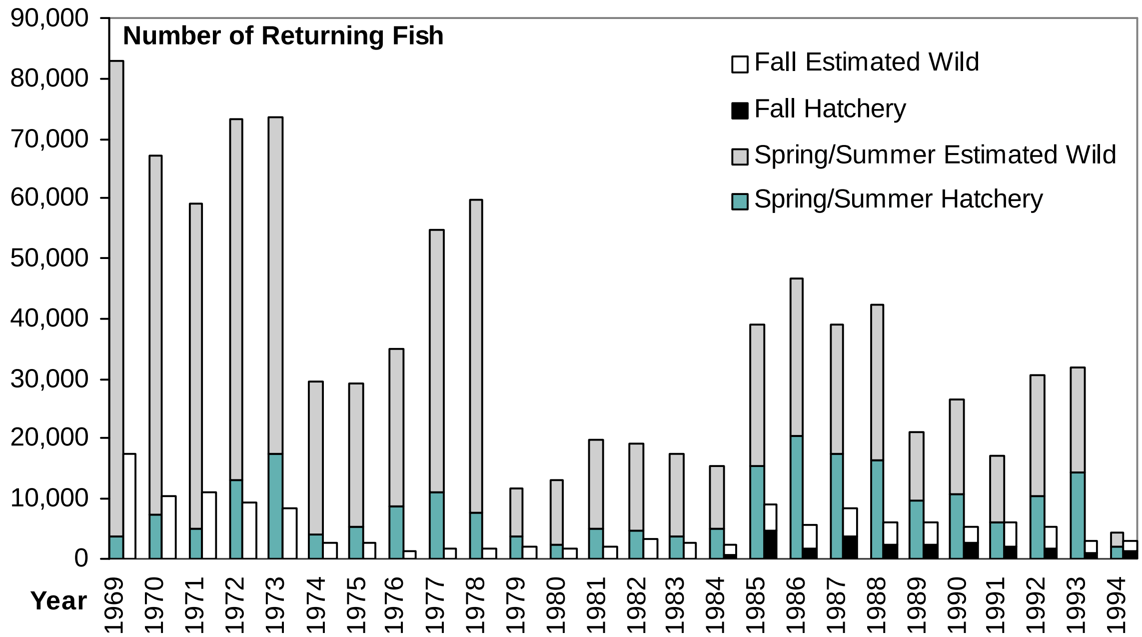


Figure 2. History of Returning Adult and Jack Spring/Summer and Fall Chinook Salmon
Source: WDFW/ODFW, 1996.

1.2 - NMFS Biologic Opinions

As the agency responsible for recovery of the Snake River salmon, the National Marine Fisheries Service (NMFS) conducted consultation for the Federal Columbia River Power System (FCRPS) under Section 7 of the ESA. The first of several "immediate actions" listed in the resulting Biological Opinion (NMFS, 1995a) to "improve survivals" was the following:

> 1. Improve flows in the Columbia and Snake Rivers through additional flow augmentation, and manage those flows on an in-season basis to optimize fish survival.
>
> . . . .
>
> . . . [The] goal [is] meeting a seasonal average flow objective at the locations and for the time periods as specified below.
>
> . . . .

	Snake River at Lower Granite Dam		Columbia River at McNary Dam	
Spring	4/10-6/20	85-100 kcfs	4/20-6/30	220-260 kcfs
Summer	6/21-8/31	50-55 kcfs	7/1-8/31	200 kcfs

A sliding scale based on the final April runoff forecast was incorporated with the above flow ranges to determine the flow objective for a particular year. In a subsequent Biologic Opinion (NMFS, 1997), NMFS concluded that:

> Irrigation withdrawal is the principal reason for missing flow objectives in the Snake River.
>
> > a. But for irrigation withdrawals, summer flow objectives would be met every year (100%) (with reservoirs operated for flow aug.), whereas with withdrawals, summer flow objectives are met less than fifteen percent of the time. . . .
> >
> > b. But for irrigation withdrawals, spring flow objectives would be met ninety-four percent (94%) (with reservoirs operated for flow aug.) of the time, compared to sixty-four percent (64%) with withdrawals. . . .

These statements would seem to indicate that NMFS believes that survival of the Snake River chinook salmon can not be improved unless the NMFS flow objectives are met. And since NMFS states that "[i]rrigation withdrawal is the principal reason for missing flow objectives in the Snake River" NMFS also apparently believes irrigation withdrawal is a significant reason why survival of salmon is not improving, and perhaps a significant reason for historical declines.

1.3 - Scope of Paper

This paper examines historical data to evaluate the significance of irrigation withdrawals on flows in the Snake River, the relationship between Snake River flows and an indicator of travel time for migrating juvenile chinook salmon, and the potential for flow augmentation improving travel time. The author is not a fish biologist and is not qualified to address the biological aspects of salmon survival. The author is, however, a professional engineer knowledgeable about hydrology and hydraulics. Consequently, the author's remarks are confined to hydrologic and hydraulic aspects.

2.0 - Historical Data

2.1 - Comparison Between Returning Chinook Salmon and Irrigated Acreage

Figure 3 portrays the counts of adult and jack spring and summer chinook and fall chinook salmon returning to the Snake River since 1969, as previously shown in Figure 2. Along with portraying the fish counts in a different format, "snapshots" of the history of the amount of irrigated acreage in the Snake River Basin above Lewiston, Idaho (including acreage in Idaho, Nevada, Oregon, Utah, Washington, and Wyoming) are superimposed. Approximately 80 percent of the irrigated acreage is in Idaho.

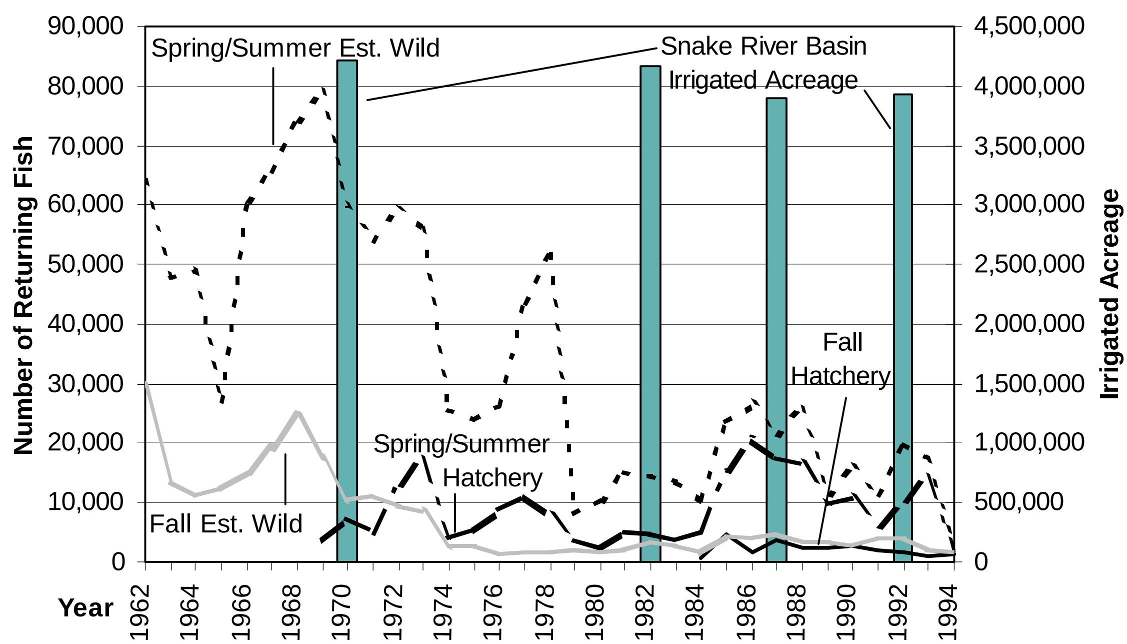


Figure 3. History of Returning Adult and Jack Chinook Compared with Snake River Basin Irrigated Acreage
Sources: WDFW/ODFW, 1996; PNRBC, 1971; and Idaho Dept. Of Commerce, 1994.

The preceding figure does not show any discernable correlation between returning adult/jack chinook salmon and irrigated acreage, which has remained relatively constant for the past 25 years. However, if the development of irrigated agriculture has contributed in any significant way to the declines in salmon populations, 25 years of history may not be sufficient to detect such effect. Documented counts for Snake River chinook salmon are not available prior to 1962. Consequently, it is not possible to quantitatively compare salmon counts and irrigated acreage over the entire history of irrigation in the Snake River Basin.

2.2 - Comparison Between Historic Snake River Flows and Irrigated Acreage

Although documented counts for Snake River chinook salmon are not available prior to 1962, data for historical flows in the Snake River are available back to the early 1900s. This provides for a quantitative comparison between historical flows and irrigated acreage.

For the purpose of making this comparison, flows at the location of the upstream end of the reservoir formed by Lower Granite Dam, just downstream of the confluence between the Clearwater and Snake Rivers at Lewiston, Idaho, are considered. Although the confluence of the Clearwater and Snake Rivers is located approximately 140 miles upstream of the Snake River's confluence with the Columbia River, this location is appropriate for such a comparison because:

1. This location is downstream of nearly all diversions for irrigation in the Snake River Basin, and return flows from that irrigation;

2. This location is downstream of the last major tributary to the Snake River, the Clearwater River;

3. This location is downstream of the Salmon River drainage which has no dams and provides extensive habitat for spawning spring and summer chinook salmon, and large portions of that habitat (approximately 80 percent of available habitat) remain in good to excellent condition (IDFG, 1992); and

4. NMFS has specified flow objectives for the Snake River at this location.

Figure 4 shows a comparison of historic irrigated acreage and historic flows in the Snake River entering the location of the reservoir formed by Lower Granite Dam near Lewiston, Idaho. For the years preceding the construction of Lower Granite Dam, flows measured at Clarkston, Washington are shown. For the years following the construction of Lower Granite Dam, the river flows are computed by adding flows from the Clearwater River to flows in the Snake River at the Clearwater/Snake confluence.

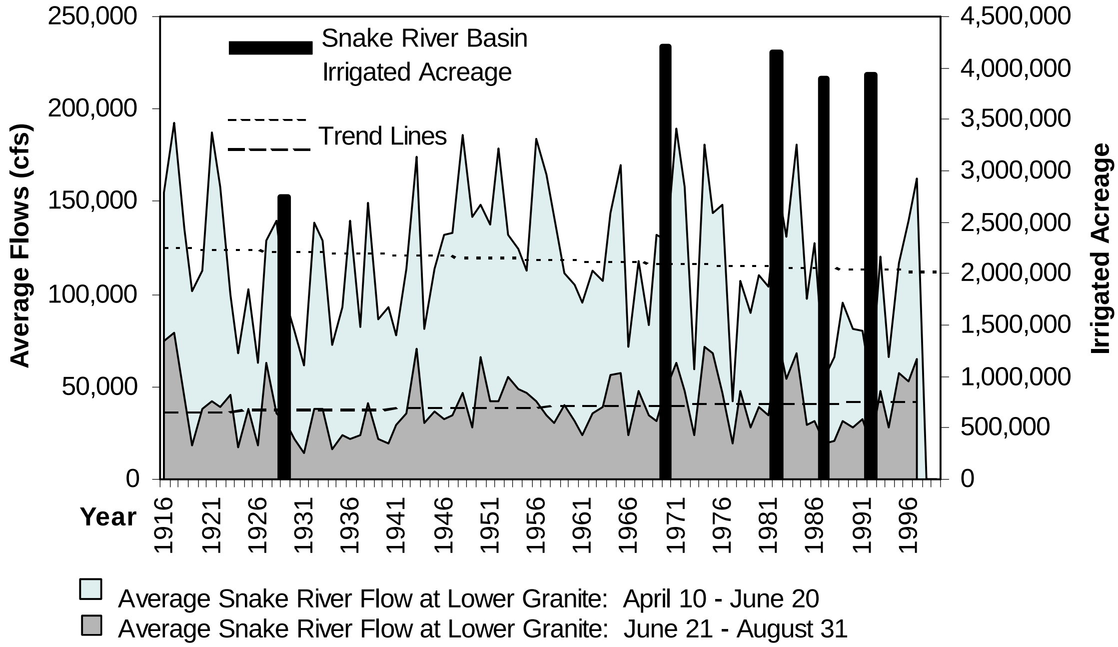


Figure 4. Snake River Flows Near Lewiston, Idaho Compared with Irrigated Acreage in the Snake River Basin
Source: USGS, 1916-1997; USGS, 1935; PNRBC, 1971; and Idaho Dept. Of Commerce, 1994.

The Snake River flows shown in Figure 4 are the averages of the average daily flows during the two 72-day time periods for which NMFS has specified flow objectives at Lower Granite Dam: April 10 through June 20, and June 21 through August 31. Despite the increase in irrigated acreage in the Snake River Basin from about 2.8 million acres in 1929 to about 4.0 million acres in the 1970s, 1980s, and 1990s, there has been no significant changes to flows at the location of Lower Granite Dam during either of the time periods for which NMFS established flow objectives. From 1916 through 1997, the average daily flow from April 10 through June 20 has consistently varied from about 70,000 cfs to about 180,000 cfs, more or less, and the average daily flow from June 21 through August 31 has varied from about 20,000 cfs to about 70,000 cfs, more or less.

As an aid to evaluating the historical flows for trends, a linear trend line was calculated for the flows in each of the time periods for which NMFS established flow objectives. These trend lines are shown in Figure 4 as a line of short dashes for the flows during the April 10 through June 20 time period and as a line of long dashes for the flows during the June 21 through August 31 time period.

The trend line for the spring flow period shows a slight decrease from 1916 to 1997. However, this decrease is about ten times less than the naturally occurring variations between low flows and high flows during the time period for the spring flow objective set by NMFS. Note that during this flow objective period, irrigation diversions would not be at maximum capacities during most years. Therefore, the reason for the slight decrease in trend during this flow objective time period is not irrigation, but rather the effect of storing water in reservoirs in the Snake River Basin upstream of the reservoir formed by Lower Granite Dam.

Interestingly, the trend line for the summer flow period shows a slight increase from 1916 to 1997. That is, during the June 21 through August 31 period for the summer flow objective set by NMFS, flows in the Snake River at Lower Granite Dam tend to be slightly higher at the present time than in the first half of the twentieth century, and this is during the time period when irrigation diversions would be expected to be at a maximum. The reason for this slight increase is the release of water stored in reservoirs in the Snake River Basin upstream of Lower Granite for diversion by irrigators and for other uses, which results in higher flows in the Snake River than would occur without the release and use of stored water.

The point of these comparisons is that the development of irrigated agriculture and the construction and operation of reservoirs in the Snake River Basin (above the reservoir formed by Lower Granite Dam) have insignificantly changed the flows in the Snake River at Lower Granite Dam during the two time periods established by NMFS as being critical to migrating juvenile chinook salmon. If the flows in the Snake River during these two time periods affect salmon survival, then irrigated agriculture and related activities in the Upper Snake River Basin have contributed very little, if anything, to the declining salmon populations. Furthermore, the declines in salmon populations can not be the result of changes in Snake River flows, as measured at Lower Granite, because the flows have not changed. Consequently, flow augmentation is not necessary to maintain historical levels of flow in the Snake River at Lower Granite Dam.

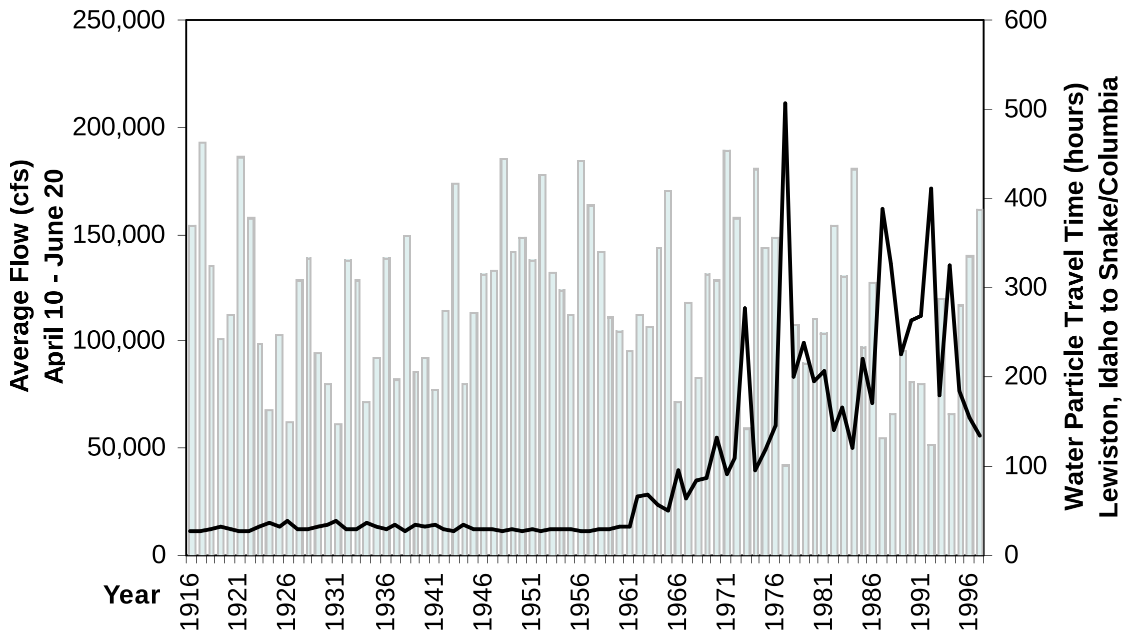
3.0 - Water Particle Travel Time and Equivalent Average Velocity

If flows in the Snake River have not significantly changed at the location of Lower Granite Dam since the early 1900s, then what has changed? One factor that has changed significantly, particularly since the 1960s as the declines in returning spring and summer chinook seem to have accelerated, is the average velocity of water flowing in the lower reach of the Snake River. Figure 5 shows the average daily flows in the Snake River since 1916 at the location of the reservoir formed by Lower Granite Dam during the time period set by NMFS for the springtime flow objective. Superimposed is a parameter termed "water particle travel time."

3.1 - Description of Water Particle Travel Time and Equivalent Average Velocity

Water particle travel time is the theoretical length of time that it would take a particle, suspended in a volume of water flowing at a given rate, to travel some specified distance. Water particle travel time can be calculated by determining the total volume of water within a particular river segment at a particular rate of flow, and dividing that volume of water by the corresponding volumetric rate of flow. For the conditions represented in Figure 5, the average daily flow during the spring flow objective period for a particular year is the given volumetric rate of flow. The specified distance is the length of the river segment between the confluence of the Clearwater and Snake Rivers to the confluence of the Snake and Columbia Rivers, about 140 miles. As an example, Figure 5 shows an average water particle travel time of about 30 hours for the years 1916 through 1961. This is the theoretical length of time for a suspended particle to travel the 140 miles from near Lewiston, Idaho to the confluence between the Snake and Columbia Rivers prior to 1962. This implies an equivalent average velocity of 140 miles per 30 hours, or about 4.7 miles per hour.

Figure 5. History of Flows Near Lewiston, Idaho During Spring Flow Objective Period



and Water Particle Travel Time to Snake/Columbia Confluence
Flow Data Source: USGS, 1916-1997.

3.2 - Comparisons Between Historic Snake River Flows and Water Particle Travel Time, or Equivalent Average Velocity

Most notable from the comparison in Figure 5 between average flows in the Snake River and water particle travel time is that the water particle travel time averaged about 30 hours with relatively little variation for the years 1916 through 1961, which preceded the construction of the four dams on the Lower Snake River below Lewiston, Idaho. This means that during the time period set by NMFS for the spring flow objective, the water particle travel time and equivalent average velocity through the lower reach of the Snake River remained nearly constant for these years and was only weakly correlated with or dependent on variations in flow, which ranged from about 70,000 cfs to 180,000 cfs.

Figure 6 shows the same type of comparisons between historical flows in the Snake River near Lewiston, Idaho and water particle travel time to the confluence between the Snake and Columbia Rivers for the summer flow objective time period established by NMFS, June 21 through August 31. The water particle travel time for the NMFS summer flow objective period averaged about 55 hours for the years 1916 through 1961, again with relatively small variations. The average water particle travel time during these years implies an equivalent average velocity of about 2.5 miles per hour. As for the spring flow objective period, the variations in water particle travel time and equivalent average velocity through the lower reach of the Snake River for the NMFS summer flow objective period were relatively small in comparison to variations in flow, which ranged from about 20,000 cfs to 70,000 cfs.

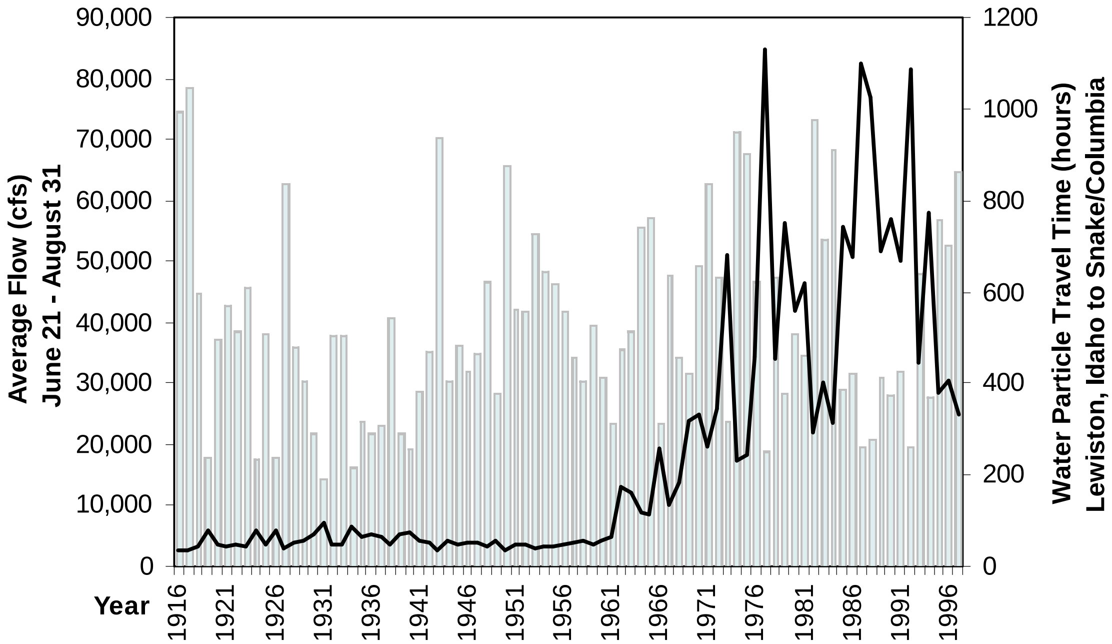


Figure 6. History of Flows Near Lewiston, Idaho During Summer Flow Objective Period and Water Particle Travel Time to Snake/Columbia Confluence
Flow Data Source: USGS, 1916-1997.

3.3 - Comparisons Between Water Particle Travel Time, or Equivalent Average Velocity, and the Construction of Dams on the Lower Snake River

Although water particle travel time is relatively short, and the equivalent average velocity is relatively high and only weakly correlated with or dependent on flows for the time period preceding the construction of the four dams on the Lower Snake River below Lewiston, Idaho, this is not the case for the period of time following completion of the dams. Figures 7 and 8 show historic water particle travel times compared with the completion of construction of the four dams on the Lower Snake River for both the spring and summer NMFS flow objective time periods.

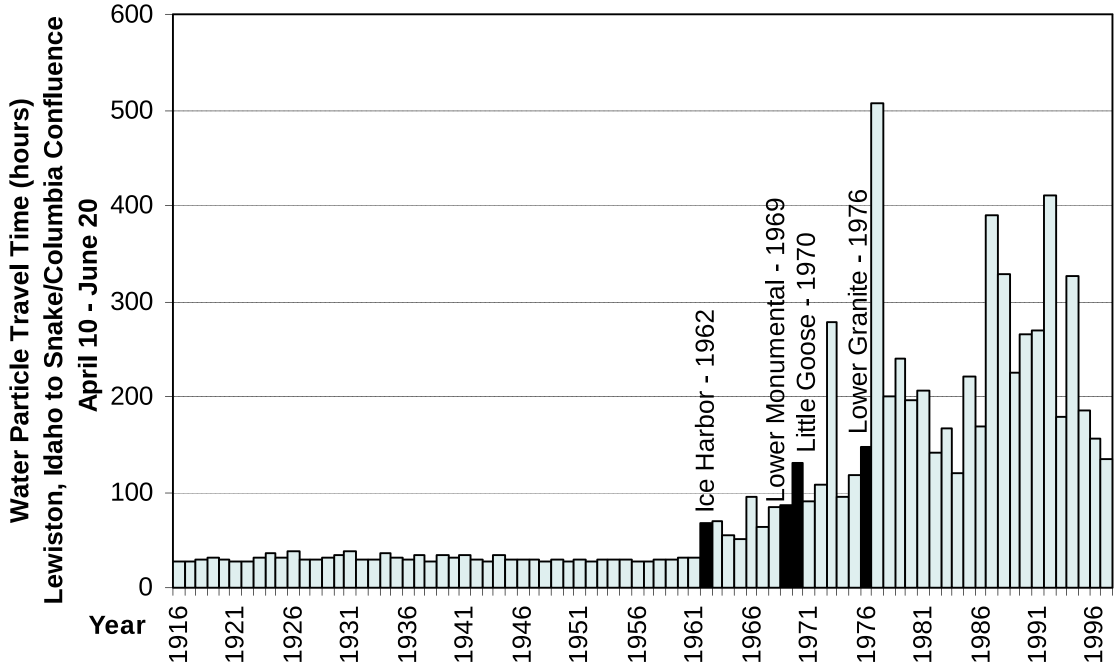


Figure 7. Water Particle Travel Time to Snake/Columbia Confluence During Period for NMFS Spring Flow Objective and History of Dam Construction

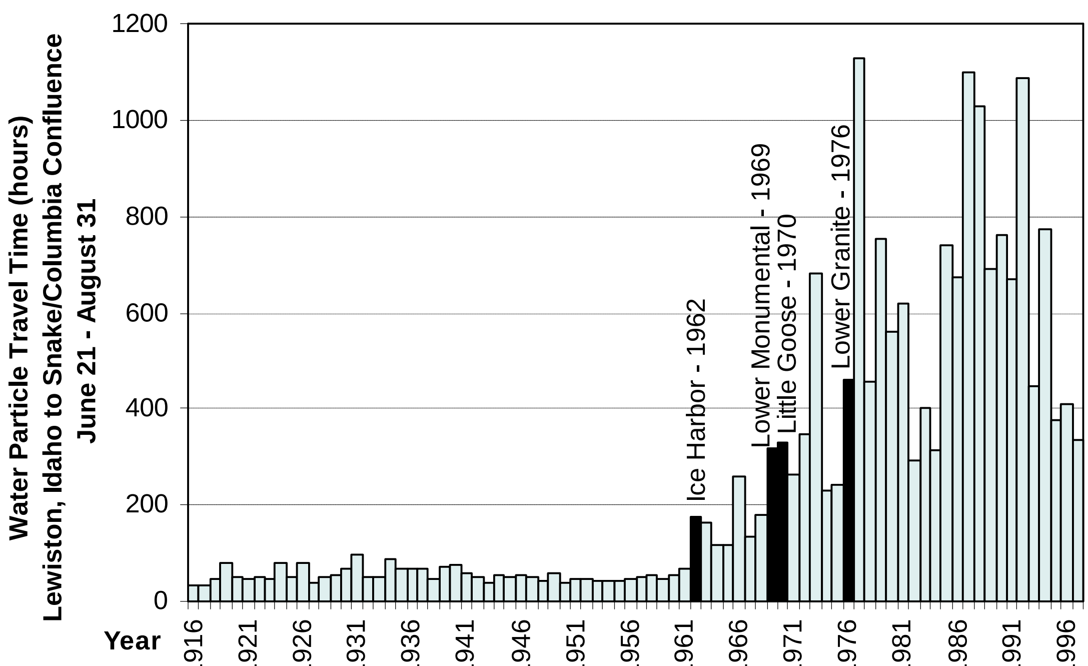


Figure 8. Water Particle Travel Time to Snake/Columbia Confluence During Period for NMFS Summer Flow Objective and History of Dam Construction

3.4 - Changes in Water Particle Travel Time and Equivalent Average Velocity Following the Construction of Dams on the Lower Snake River

A volumetric rate of flow is the product of two components, cross-sectional area of the flow and velocity of the flow. Consequently, even when the velocity of flow remains constant, a change in the rate of flow can occur and will be directly proportional to a change in the cross-sectional area of the flow.

As previously shown, prior to the construction of the four dams on the Snake River below Lewiston, Idaho, the dependency or correlation of water particle travel time and equivalent average velocity between Lewiston and the confluence of the Snake and Columbia Rivers with flows in the Snake River was relatively small. Prior to 1962, the equivalent average velocity was primarily dependent on the gradient of the Snake River. Even though flows during a particular time period varied dramatically from year to year, based solely on natural hydrologic conditions, variations in the equivalent average velocity were much smaller. Large variations in flows caused large variations in the cross-sectional areas of flow, but only small variations in average velocities.

As the four dams below Lewiston were completed, the cross-sectional areas of flow and the corresponding volumes of water within the river segment containing the reservoirs that were formed were significantly greater than the cross-sectional areas of flow and corresponding volumes of water prior to construction of the dams. Hence, for a given flow through much larger cross-sectional areas, the velocities decreased in proportion to the increases in area, and water particle travel times increased dramatically. Additionally, the equivalent average velocity was no longer primarily dependent on the gradient of the Snake River. Instead, because the cross-sectional areas of flow in the reservoirs were so large, naturally occurring changes in flow because of hydrologic conditions caused relatively small changes in the cross-sectional areas of flow. Consequently, the equivalent average velocities which were not primarily a function of the rate of flow prior to construction of the dams, became significantly more dependent on the rate of flow as the dams were constructed.

3.5 - Significance of Water Particle Travel Time to Migrating Juvenile Salmon

Some readers may question whether there is any significant relationship between water particle travel time and the travel time and survival of juvenile chinook salmon during migration downstream. Aside from the biological issues, which are beyond the scope of this paper and the knowledge of its author, consider the following.

If there is no correlation between water particle travel time and the travel time and survival of juvenile chinook salmon during migration downstream, then there can be no correlation between equivalent average velocity and the travel time and survival of juvenile chinook salmon. And if there is no correlation with average velocity, then what's the purpose of flow augmentation? Assuming there is a correlation between average velocities and survival of juvenile salmon during migration downstream, then the question is how effective is flow augmentation in increasing average velocities?

4.0 - Effectiveness of Flow Augmentation for Mitigating Effective Average Velocity and Water Required for NMFS Flow Objectives at Lower Granite

4.1 - Effectiveness of Flow Augmentation for Mitigating Effective Average Velocity

Figure 7 shows that prior to the construction of the four dams on the Snake River below Lewiston, Idaho, the water particle travel time between Lewiston and the Snake River's confluence with the Columbia River was approximately 30 hours (equivalent average velocity of 4.7 miles per hour) during the NMFS spring flow objective period. Similarly, Figure 8 shows the water particle travel time was approximately 55 hours (equivalent average velocity of 2.5 miles per hour) during the NMFS summer flow objective period. Since the construction of the four dams below Lewiston, the water particle travel time during the NMFS spring flow objective period has increased and the equivalent average velocity has decreased by a factor of 5 to 10 times or more, depending on hydrologic conditions. Similarly, the water particle travel time has increased and the equivalent average velocity has decreased 10 to 20 fold during the NMFS summer flow objective period.

In order to maintain the average water particle travel times and equivalent average velocities that occurred prior to construction of the dams, flows in excess of 750,000 cfs would be required during the April 10 to June 20 time period, and flows in excess of 400,000 cfs would be required during the June 21 to August 31 time period. This equates to a volume of water required during these two time periods alone in excess of 160 million acre-feet., from a river basin which only produces a total average annual runoff volume of 37 million acre-feet. While the results of these hypothetical calculations are ridiculous, they serve to illustrate the futility of using flow augmentation to neutralize the reductions in average flow velocities that occur through the four reservoirs below Lewiston.

As an additional indication of the futility of using flow augmentation to mitigate velocity reductions, consider the result of meeting the flow objectives set by NMFS for the summer flow objective period of June 21 through August 31. During this time period, NMFS presently sets a flow objective of 50,000 to 55,000 cfs at Lower Granite. The average historical flow in the Snake River upstream of Lower Granite is 39,400 cfs for the years 1916 through 1997. Thus in a year of average runoff, there would be insufficient flows to meet the NMFS flow objective for June 21 to August 31. If flow augmentation is used to provide a flow of 55,000 cfs in such an average year, a water volume of 2.2 million acre-feet would be required (presently, approximately 1.5 million acre-feet of water for flow augmentation is taken out of Idaho annually). Meeting the flow objective of 55,000 cfs would result in a travel time of 390 hours, or an equivalent average velocity of less than 0.4 miles per hour. Even though meeting the NMFS summer flow objective would reduce the water particle travel time by about 150 hours and increase the effective average velocity by about 0.1 miles per hour, the water particle travel time would still be 7 times greater and the effective average velocity would be 7 times less than what would have occurred prior to the construction of the four dams below Lewiston. Consequently, the levels of flow augmentation considered necessary by NMFS provide relatively small incremental improvements to average velocities.

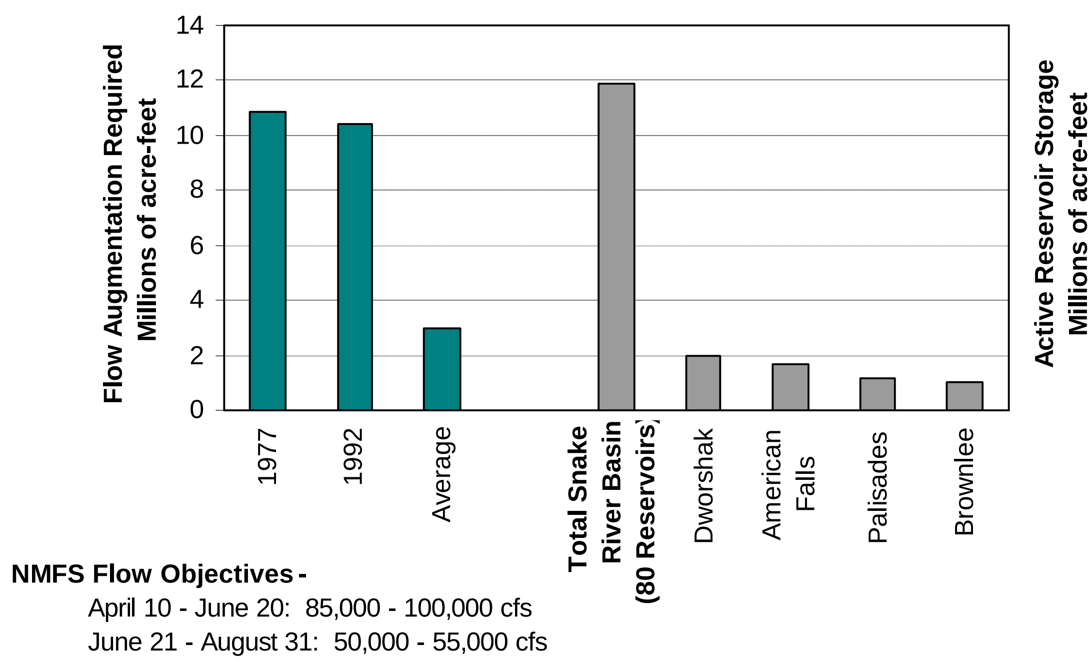
4.2 - Volume of Water Required for NMFS Flow Objectives at Lower Granite

The average historical flow in the Snake River upstream of Lower Granite Dam for the years 1916 through 1997 is 119,400 cfs during the time period established by NMFS for its spring flow objective. This exceeds the NMFS spring flow objective of 85,000 cfs to 100,000 cfs, and flow augmentation would presumably not be used during this time period in years of average or better runoff conditions. However, in a dry year such as 1987 (which is not the driest year of record) when the average flow during the NMFS spring flow objective period was only 55,300 cfs, a water volume of 4.2 million acre-feet would be required to meet a flow objective of 85,000 cfs.

As described previously, the average historical flow for the years 1916 through 1997 is 39,400 cfs upstream of Lower Granite Dam during the time period NMFS has set for the summer flow objective. This average flow is less than the NMFS summer flow objective of 50,000 cfs to 55,000 cfs and would require 2.2 million acre-feet of water for flow augmentation to meet the 55,000 cfs objective. In a dry year such as 1987 when the average flow during the NMFS summer flow objective period was only 19,500 cfs, 4.4 million acre-feet of water would have been required for flow augmentation to meet a flow objective of 50,000 cfs.

Figure 9 shows the volume of water required to meet the NMFS flow objectives in an average year (based on a longer term average than for the years 1916 through 1997) and two dry years other than 1987. The volumes of water required are shown in comparison to reservoir storage volumes in the Snake River Basin, including Dworshak Reservoir.

Figure 9. Volume of Water Required to Meet NMFS Flow Objectives at Lower Granite Dam



Aside from the conclusion that flow augmentation to meet the flow objectives established by NMFS provides relatively small incremental improvements to average velocities, the volumes of water required would use all of the active reservoir storage available in the Snake River Basin. This means that uses of water for which Congress authorized the construction of the federally-owned dams and reservoirs above Lewiston would either have to cease or be made subordinate to use of all of the water to augment flows. Even then, the NMFS flow objectives could not be met every year because of the NMFS policy to augment flows whenever flows fall below target levels, even in years of average to somewhat above average runoff conditions. This policy, if implemented, would result in drawing down reservoir storage in years preceding dry-year sequences during which the active reservoir storage could not be refilled. Consequently, in a series of dry years, such as occurred in 1987 through 1994, there would not be sufficient reservoir storage to meet flow objectives every year. To the extent there are any benefits to migrating juvenile chinook salmon from augmenting flows, augmentation should be limited to dry years when flows would otherwise be the lowest.

5.0 - Conclusions

1. The development of irrigated agriculture, the construction of dams on the Snake River upstream of Lower Granite Dam, and the regulation of the Snake River above Lewiston, Idaho, have not:

   a. Significantly decreased flows in the Snake River below Lewiston, Idaho during the 72-day time periods in the spring and summer for which NMFS has specified flow objectives;

   b. Resulted in significant increases in water particle travel times or decreases in equivalent average velocities between Lewiston, Idaho, and the confluence of the Snake and Columbia Rivers; and

   c. Significantly impeded out-migration of juvenile salmon or in-migration of adult salmon to remaining habitat.

2. The construction of the lower four dams on the Snake River (Ice Harbor, Lower Monumental, Little Goose, and Lower Granite) have:

   a. Resulted in significant increases in water particle travel times and decreases in equivalent average velocities in the Snake River between Lewiston, Idaho and the confluence of the Snake and Columbia Rivers;

   b. Resulted in significant hydraulic changes both of which impede the out-migration of juvenile salmon and in-migration of adult salmon.

3. The impedance caused by the lower four dams on the Snake River is not rate-of-flow related and therefore, the impedance can not be overcome with rate-of-flow actions - ie., flow augmentation.

4. Flow augmentation can provide only small incremental improvements in average velocities. However, the improvements are not significant, particularly during the NMFS spring flow objective period when higher flows occur which reduce any effectiveness of flow augmentation.

5. The Snake River Basin does not yield water in sufficient quantities to meet the NMFS flow objectives in all years. To the extent there are other benefits to migrating salmon from augmenting flows not considered in this paper, flow augmentation should be primarily limited to dry years when flows would otherwise be the lowest.

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